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SOIL-VEGETATION CORRELATIONS IN WETLANDS AND ADJACENT UPLANDS OF THE SAN FRANCISCO BAY ESTUARY, CALIFORNIA

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PREFACE

The National Ecology Research Center of the U.S. Fish and Wildlife Service (FWS) is supporting a series of field research studies to document relationships between hydric soils and wetland vegetation in selected wetlands throughout the United States. This study is one of that series. It is a continuation of the FWS effort, begun by Wentworth and Johnson (1986), to develop a procedure using vegetation to designate wetlands based on the indicator status of wetland vegetation as described by the FWS "National List of Plants that Occur in Wetlands" (Reed 1986). This list classifies vascular plants into one of five categories according to their frequency of occurrence in wetlands. Concurrent with the development of the wetland plant list, the Soil Conservation Service (SCS) developed a National List of Hydric Soils (SCS 1985a). Studies supported by the National Ecology Research Center quantitatively compare associations of plant species, designated according to their hydric nature using the Wentworth and Johnson (1986) procedure, with the hydric nature of soils according to their designation on the SCS hydric soils list. The studies are being conducted across moisture gradients at a variety of wetland sites throughout the U.S. Several studies have been modified to obtain concommitant information on groundwater hydrology.

These studies were conceived in 1984 and implemented in 1985 in response to internal planning efforts of the FWS. They parallel, to some extent , ongoing efforts by the SCS to delineate wetlands for Section 1221 of the Food Security Act of 1985 (the swampbuster provision). The SCS and FWS provided joint guidance and direction in the development of the Wentworth and Johnson (1986) procedure, and the SCS is currently testing a procedure that combines hydric soils and the Wentworth and Johnson procedure for practical wetland delineation. The efforts of both agencies are complimentary and are being conducted in close cooperation.

The primary objectives of these studies are to (1) assemble a quantitative data base of wetland plant community dominance and codominance for determining the relationship between wetland plants and hydric soils; (2) test various delineation algorithms based on the indicator status of plants against independent measures of hydric character, primarily hydric soils; and (3) test, in some instances, the correlation with groundwater hydrology. The results of these studies also can be used, with little or no supplementary hydrologic information, to compare wetland delineation methods of the Corps of Engineers (Environmental Laboratory 1987) and the Environmental Protection Agency (Sipple 1987).

Any questions or suggestions regarding these studies should be directed to Charles Segelquist, U.S. Fish and Wildlife Service, 2627 Redwing Road, Fort Collins, CO 80526-2899; FTS 323-5384 or Commercial (303) 226-9384.

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A number of people were helpful in arranging access to study sites, providing general information about the sites, and describing seasonal hydrologic patterns for specific locations. Among others, this list includes Richard Coleman, Richard Munoz, and Tom E. Harvey, FWS San Francisco Bay National Wildlife Refuge; Chuck Graves and Dennis Becker, California Department of Fish and Game; Ron Brean, Glenn Ryburn, and Jim Phillips, California Department of Parks and Recreation; Ron Russo and Mark Taylor, East Bay Regional Park District; and H. Thomas Harvey, Harvey and Stanley Associates.

Soil determinations were made in the field by Donald White, SCS, Santa Rosa, CA, and John Weatherford, SCS, Sacramento, CA. Statistical analyses were performed by Bill Slauson, FWS National Ecology Research Center.

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INTRODUCTION

In recent years, numerous Federal, State, and local regulations have been generated regarding the use and protection of wetlands--a dwindling land type now recognized as having considerable ecological and socioeconomic value. Interpretation of these regulations has been difficult in many cases because of confusion over what constitutes a wetland and where the boundary between wetland and upland lies. The U.S. Fish and Wildlife Service (FWS) wetland classification system (Cowardin et al. 1979) incorporates the following definition:

> Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For purposes of this classification wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year.

According to this definiton, if an area has any one of the three attributes listed, it qualifies as a wetland. The first attribute refers to the presence of plants that are typically associated with wetland conditions. The term 'hydrophyte' is defined by the Soil Conservation Service (SCS 1986) as "... a plant growing in: (1) water; or (2) a substrate that is at least periodically deficient in oxygen during a growing season as a result of excessive water content." If an area is covered primarily by hydrophytic vegetation (i.e., hydrophytes), then it meets the definition of wetland, even if such coverage is seasonal, as in the case of vernal pools.

The second attribute refers to the presence of hydric soils. The SCS (1985b) has developed specific criteria for qualifying hydric soils (Appendix A), based on the following definition: "A hydric soil is a soil that in its undrained condition is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation."

The third attribute allows for the inclusion of areas without soil that qualify as wetlands on the basis of hydrologic regime, e.g., a rocky intertidal shore.

Definitions alone are not enough for making wetland determinations. It is necessary to develop standard methodologies for applying these definitions in the field. This study is one in a series of studies sponsored by the National Ecology Research Center of the FWS to document the relationship between hydrophytes and hydric soils in a variety of field situations. The wetland types selected for this study are the tidal marshes and diked former tidal marshes of the San Francisco Bay estuary, California. These wetlands have been highly modified by widespread human development. Conomos (1979) aptly characterized San Francisco Bay as "the urbanized estuary."

Vegetation and soils were sampled in wetlands and in adjacent upland areas. Each plant species was assigned an indicator value representing its frequency of occurrence in wetlands, according to a national list prepared by the FWS (Reed 1986). These plant indicator values were used to rank sample plots on a wetland-upland gradient, according to a procedure developed by Wentworth and Johnson (1986). The results were then compared to the hydric status of the associated soils and to hydrologic conditions at the study sites.

STUDY AREA

The San Francisco Bay estuary is the largest estuarine system in California. The estuary consists of three basins: Suisun, San Pablo, and San Francisco Bays (Figure 1). San Francisco Bay extends as far north as Point San Pedro. The channel linking San Pablo Bay with Suisun Bay is called Carquinez Strait. The Sacramento-San Joaquin drainage basin, which covers over 40% of the land area in California, empties into Suisun Bay from the east through a low-lying delta area.

The development of tidal marshes along the margins of the San Francisco Bay estuary has occurred within the last 6,000 years, as sediments were deposited and stabilized by the establishment of marsh plants. By 1850, tidal marshes covered an estimated 2,200 km^2, nearly twice as much area as the open water surface of the bay (Atwater et al. 1979). Since then, over 95% of these tidal marshes have been diked or filled. Early diking was most extensive in the Sacramento-San Joaquin Delta, where the rich, organic marsh soils were well-suited for agricultural use. The marshes around Suisun and San Pablo Bays were diked primarily for grazing and growing grain and row crops. The high salinity of marsh soils in San Francisco Bay made them less desirable for agricultural conversion, and the first interest in diking marshes in this area was for use as salt evaporation ponds. Later, many of the estuary's tidal marshes were filled for residential and industrial developments, sewage treatment facilities, and garbage dumps. About 40 km^2 of existing tidal marsh has developed in the estuary since 1850, largely as the result of accelerated rates of sedimentation caused by hydraulic mining for gold in the Sierra Nevada in the late 1800's (Atwater et al. 1979).

The tidal marshes of the San Francisco Bay estuary, including the Delta, covered approximately 144 km^2 in 1985, based on photointerpretation by the FWS National Wetlands Inventory. Diked former tidelands that continued to support wetland vegetation or contained seasonal or permanent ponds were estimated at 291 km^2. Another 321 km^2 were mapped as 'farmed wetlands' (Handley 1987a and 1987b; L. Handley, FWS; pers. comm.).

San Fransisco Bay estuary tidal marshes can be characterized as relatively flat plains which tend to increase slightly in elevation at the border of sloughs and in some cases at the shoreline. The elevation of these marsh plains is generally near the mean high tide level. Older marshes, formed before 1850, typically have extensive, sinuous tidal channels; younger marshes tend to have channels with straighter paths (Pestrong 1972). From aerial photos, Cuneo (1987) calculated an average of 32 mi of drainage channel per mi^2 of marsh (20 km channel/km^2 marsh) in the San Francisco Bay estuary.

Historically, the estuary's tidal marshes were bordered by alluvial fans, flood plains, basins, and terraces skirting the foothills of the Coast Ranges that lie to the north and east. Prior to widespread reclamation practices, the basins were frequently wet, and they supported typical wetland vegetation. Basin rims were covered by upland perennial grasses, with a transition to oak woodland on the adjacent hillsides (SCS 1972, 1977a, 1977b, 1981, 1985d). The historic landscape pattern has since been fragmented by widespread urbanization. Development has encroached to the edges of the bay in many spots, and the transition area lands lying between the bay and the mountains have been highly modified. Most remaining tidal marshes are terminated abrubtly at their upper margins by dikes. Consequently, examples of natural transitions from marsh to upland are rare.

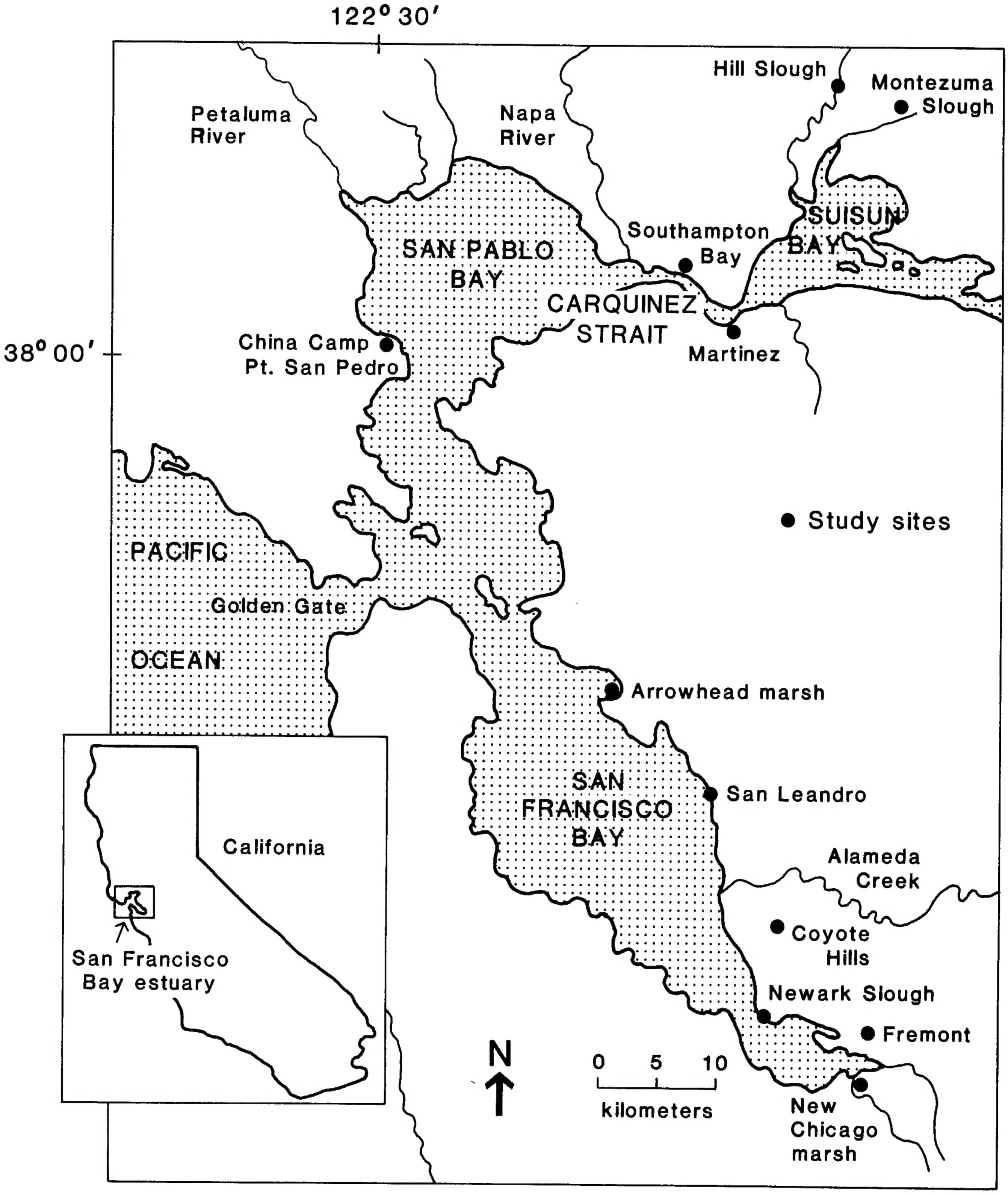

Figure 1. Map of study area: the San Francisco Bay estuary, California, showing the location of eleven sites where soils and vegetation were sampled.

The tidal cycle in the San Francisco Bay estuary has a mixed semidiurnal pattern, characterized by two high tides of unequal magnitude and two low tides of unequal magnitude every day. Tidal exchange between the Pacific Ocean and the estuary occurs through the Golden Gate (Figure 1). Overall, about 24% of the bay's water is exchanged every 12.5 hours (Jones and Stokes Assoc. et al. 1979). Circulation patterns within the bay are driven by tidal exchange and freshwater inflow. The main sources of freshwater inflow are the Sacramento and San Joaquin Rivers which flow into Suisun Bay from the east. Smaller tributatries include the Napa and Petaluma Rivers flowing into San Pablo Bay, and Coyote Creek flowing into San Francisco Bay (Figure 1).

The San Francisco Bay area has a temperate-marine climate, with cool, moist winters and warm, dry summers. Mean annual temperatures for various locations around the bay are between 12-16 °C, with mean monthly temperatures ranging from 7 °C in winter to 23 °C in summer. Generally, cooler temperatures are associated with higher elevations. Precipitation tends to increase inland with increasing elevation, and is generally greater in the northern bay area then in the southern region, with mean annual estimates ranging from 33-63 cm for different locations. About 95% of this precipitation occurs between October and April. Average relative humidity near the bay remains near 80% year round. Inland, relative humidity ranges from 60% in the summer to 75% in the winter (SCS 1972, 1977a, 1977b, 1981, 1985d).

SOILS

Most of the bedrocks underlying the San Francisco Bay estuary belong to the Franciscan Formation, which is predominantly a sequence of sandstones and shale, with lesser amounts of chert, greenstone, and other rocks (San Fransisco Bay Conservation and Development Commission 1967). Over the years, the rock bay basin has been overlaid by sedimentation. Bay sediments are fine-grained and uniform in texture, consisting of about 75%-85% clay and the remainder silt. Sediments are deposited along the bay shore in areas where tidal currents are slow. Channels are cut by the ebb flow of tidewaters draining off the mudflat. Vascular plants that colonize the mud trap additional sediments, and the surface elevation slowly increases. Expanding plant colonization influences the pattern of drainage channel formation, and plant root growth helps stabilize channel banks (Pestrong 1972; Madrone Assoc. et al. 1982).

San Francisco Bay estuary tidal marsh soils are mostly mixtures of hydrophytic plant remains and mineral sediments, varying in their ratio of organic/mineral content. Mineral soils are found on the bay shoreline and adjacent to sloughs, where mineral sediments are deposited by tidal waters and turbulent floodwaters. Organic soils are found further from sloughs, often at lower elevations with poorer drainage, where the accumulation of partially decomposed plant material forms organic deposits (SCS 1977b).

The predominant soil type occurring in the tidal marshes of San Pablo and San Francisco Bays is a mineral soil called Novato. In soil surveys published before 1985, this soil type was mapped as Reyes. Reyes soils were redefined in 1985 to include only those areas where diking and drainage have significantly altered soil characteristics (SCS 1985c). Reyes soils are more compacted than Novato soils. The consolidation of soil particles caused by drying is evident as soil shrinkage and subsidence. Drops of 3 to 5 ft in elevation have been noted (Madrone Assoc.et al. 1982). High acidity further distinguishes Reyes from Novato soils, which are moderately to strongly alkaline. Acid conditions develop as a result of oxidation when previously saturated, anaerobic marsh soils are dried and exposed to air. Hypersalinity is another common result of draining tidal marsh soils. Without tidal flushing, salts accumulate in the soil and concentrate at the surface during summer evaporation. Winter rainfall and ponding may leach salts from the soil, but if the leachate cannot drain, the salts remain. (Madrone Assoc. et al. 1982). In summary, Reyes soils have lower soil moisture content than Novato soils, greater compaction, a higher pH, and generally higher salinities.

The distribution of Novato soils extends into Suisun Bay, where it is joined by three organic tidal marsh soil types. In order of increasing organic content, these are Tamba, Joice, and Suisun. The most widespread soil types in Suisun Bay tidal marshes are Joice and Novato (SCS 1977a, 1977b). The effects of drainage described for Novato are similar for other tidal marsh soils, but only in the case of Novato has a separate soil series been recognized for the drained condition (i.e., Reyes).

Other soil types in the San Francisco Bay area that support salt and brackish marsh species include Omni, Pescadero, Marcuse, Solano, Alviso, and Valdez. Omni soils occur in flood plains and basins, and Pescadero soils on basin rims around the bay. In Contra Costa County, Marcuse and Solano soils are found on basin rims. In Solano County, Alviso soils are distributed along the rims of marshes, and Valdez soils occur on alluvial fans and dredge spoil areas (SCS 1972, 1977a, 1977b, 1981, 1985d). The types of soil found bordering tidal marshes around the San Francisco Bay estuary are numerous, and the reader is referred to local county soil survey reports (SCS 1972, 1977a, 1977b, 1981, 1985d). The soil series sampled in this study are described in Appendix B.

VEGETATION

Hinde (1954) was one of the first to describe the vegetation of San Francisco Bay tidal marshes. In his Palo Alto study, he related plant distribution to tide levels, and he suggested that the observed vertical zonation of plant species was a response to different degrees of tidal submergence. Atwater and Hedel (1976) described tidal marsh vegetation in the northern part of the estuary, relating plant distribution to tide levels and water salinity. Atwater et al. (1979) provided a list of common tidal marsh species, comparing their distribution in San Francisco Bay, San Pablo Bay, Carquinez Strait, Suisun Bay, and the Delta. Josselyn (1983) prepared an ecological profile of the estuary's tidal marshes, including information on major plant species. Madrone Assoc. et al. (1982) discussed vegetation patterns in diked and undiked marshes around the bay.

The distribution and nature of tidal wetlands around the San Francisco Bay estuary are governed largely by the salinity gradient. Salinity is highest in San Francisco Bay, where tidal inflow from the Pacific Ocean is the predominant influence. Conditions are progressively less saline in San Pablo and Suisun Bays, where ocean waters mix with freshwater inflow from the Sacramento-San Joaquin Delta. As a result, San Francisco Bay tidal wetlands are characterized by salt marsh species; San Pablo Bay exhibits a transition from salt to brackish marsh species; and Suisun Bay tidal marshes are dominated by brackish species. Tidal freshwater wetlands are found in the Delta, where saline water intrudes only during the driest years (Atwater et al. 1979; Josselyn 1983).

The salt marsh community in San Francisco Bay is dominated by Pacific cordgrass (*Spartina foliosa*) and perennial pickleweed (*Salicornia virginica*). Pacific cordgrass is the primary colonist of mudflats, and generally forms monospecific stands between mean tide level (MTL) and the level of mean high water (MHW). Perennial pickleweed, occurring primarily at elevations above MHW, covers more area than any other salt marsh species in the estuary (Josselyn 1983). An orange, parasitic plant commonly found growing on pickleweed is the marsh dodder (*Cuscuta salina*). Other species associated with perennial pickleweed include fleshy jaumea (*Jaumea carnosa*) and seaside arrowgrass (*Triglochin maritimum*). At slightly higher elevations, perennial pickleweed is joined by saltgrass (*Distichlis spicata*), marsh gumplant (*Grindelia humilis*), sea lavender (*Limonium californicum*), alkali heath (*Frankenia grandifolia*), Australian saltbush (*Atriplex semibaccatta*), and orache (*Atriplex patula*) (Macdonald 1977; Atwater et al. 1979; Josselyn 1983).

In the estuary's brackish marshes, California bulrush (*Scirpus californicus*) is dominant at low elevations. Mid-elevations are characterized by cattails (*Typha angustifolia* and *T. latifolia*), alkali bulrush (*Scirpus robustus*), and Olney's bulrush (*Scirpus americanus*). A variety of species are found at higher

elevations, including Baltic rush (*Juncus balticus*), brass buttons (*Cotula coronopifolia*), saltgrass, perennial pickleweed, marsh gumplant and orache (Atwater et al. 1979; Josselyn 1983).

When tidal marshes are diked, the hydrologic regime is altered from periodic tidal inundation to a pattern of seasonal submergence/evaporation. Dikes not only block tidal inflow but also impede the drainage of freshwater runoff, which often results in ponding after winter storms. As water evaporates, residual salts are concentrated in the soil surface. As a result of these unfavorable environmental conditions, many marsh plants die following diking. The hard crust that typically forms on the soil surface after drying, together with soil compaction, further inhibits plant germination and root penetration. Where uncultivated, the vegetation of diked former tidelands consists primarily of perennial pickleweed. Pacific cordgrass is eliminated by diking. The cordgrass is less tolerant of high soil salinity than pickleweed (Mahall and Park 1976), and cannot withstand prolonged submergence of the root zone (Madrone Assoc. et al. 1982). Species that sometimes occur with pickleweed in diked areas include alkali heath, saltgrass, brass buttons, and orache. Along the upper margins of diked wetlands, these marsh species are joined by ruderal (i.e., weedy) annual grasses and forbs.

ECOLOGICAL SIGNIFICANCE

The marshes, mudflats, and open water of the San Francisco Bay estuary provide an essential resting place, feeding area, and wintering grounds for millions of birds on the Pacific Flyway from Canada to Mexico. The reduced availability of estuarine habitat along the Pacific Coast has become a limiting factor to the populations of many western North American shorebirds (Jones and Stokes Assoc. et al. 1979). The San Francisco Bay estuary supports over 100 species of fish, many of which depend on shallow intertidal areas for spawning and nursery grounds (San Francisco Bay Conservation and Development Commission 1969).

A number of marsh-dependent plant and animal species have become rare and endangered, largely as a result of habitat loss. Preservation and restoration of remaining habitat are vital to the protection of these species. As habitat for rare and endangered species, San Francisco Bay estuary tidal marshes are afforded Federal protection under the Endangered Species Act of 1973, and State protection under the California Native Plant Protection Act of 1977 and the California Endangered Species Act of 1984. The following species designations of rare, endangered, and threatened are taken from Federal listings (USFWS 1987), State listings (Calif. Dept. Fish Game 1987), and listings by the California Native Plant Society (Smith and York 1984).

Soft bird's beak (*Cordylanthus mollis* ssp. *mollis*) is listed by the California Native Plant Society as rare and endangered through portions of its range. It is listed by the State as rare, and it is a candidate species for Federal listing. This rare annual is restricted to a few populations in salt and brackish marshes along the western border of the San Francisco Bay estuary, in Richardson Bay.

Point Reyes bird's beak (*Cordylanthus maritimus* ssp. *palustris*) is listed by the California Native Plant Society as rare and endangered throughout its range. This subspecies is a candidate for Federal listing, but at present is not listed by the State. Point Reyes bird's beak occurs in coastal salt marshes along the Pacific Coast from Coos Bay, Oregon, to Morro Bay, California.

Delta tule pea (*Lathyrus jepsonii*) is listed by the California Native Plant Society as rare and endangered through portions of its range. At present, it is not on the Federal or State endangered lists. Delta tule pea grows in brackish marshes bordering Suisun Bay, and extends south of the estuary as far as Fresno County.

The California clapper rail (*Rallus longirostris obsoletus*) is a secretive marsh bird listed as endangered on Federal and State lists. The California clapper rail is a year-round resident of salt marshes bordering the San Francisco Bay estuary, and it also occurs south of the estuary at Elkhorn Slough.

The California black rail (*Laterallus jamaicensis coturniculus*) is listed by the State as threatened. At present, it is not on the Federal list. This small, secretive bird is rarely seen, making it difficult to assess its distribution and population size. Historically, the California black rail occurred in coastal salt and brackish marshes from just north of the San Francisco Bay estuary south to Baja California, and in inland freshwater marshes of the Sacramento-San Joaquin Delta.

The California least tern (*Sterna albifrons browni*), the American peregrine falcon (*Falco peregrinus anatum*), and the California brown pelican (*Pelecanus occidentalis califonicus*) are all on Federal and State endangered species lists. These bird species are not limited to marsh habitat, but all do use San Francisco Bay estuary tidal marshes.

The salt marsh harvest mouse (*Reithrodontomys raviventris*) is listed as endangered on Federal and State lists. This rare mouse is restricted to salt marshes bordering the San Francisco Bay estuary. The salt marsh harvest mouse is typically associated with dense stands of pickleweed. It is found both in tidal marshes and in diked former tidal marshes.

In undisturbed systems, the transition zone between marsh and upland is used by marsh wildlife as a refuge during high tides. Transitional habitat around the bay has been severely reduced by development. To some extent, diked former tidelands have taken on the ecological role of providing refuge areas for many wetland species. In addition, diked marshes provide protected corridors for wildlife movement between tidal wetlands. Furthermore, diked baylands function as buffer zones between the bay and urban areas (Madrone Assoc. et al. 1982).

METHODS

Sampling and analysis were conducted according to guidelines established by the National Ecology Research Center for evaluating wetland soil/plant correlations. Vegetation was sampled on nine soil series occurring in San Francisco Bay estuary tidal marshes, diked former tidelands, and bordering upland habitats. Field determinations of soil series were made by SCS soil scientists John Weatherford (at Solano County sites) and Donald White (at all other sites). Hydric designations for soils were based on the depth of the water table, observed or reported flooding or ponding, and the presence of gleying and/or mottling in the soil profile.[1] Sampling was conducted between 9 June 1987 and 17 July 1987.

STUDY SITE SELECTION

County soil surveys (SCS 1941, 1972, 1977a, 1977b, 1981, 1985d) and National Wetlands Inventory maps (USFWS 1985) were consulted in selecting study sites. Location of areas suitable for sampling was complicated by the fragmented nature of the bay's marshes, scarcity of natural transitions from marsh to upland, widespread level of disturbance and modification, and inaccessibility to certain privately owned lands. Eleven study sites were selected, most located in parks or refuges (Figure 1, Tables 1 and 2). Four sets of vegetation samples were collected as replications for each soil series. When possible, the replications were located at different sites; otherwise they were situated in different areas within the same site (Table 3).

Reyes soils were sampled at three sites in diked, former tidelands. All three sites were within the historic baylands margin, as mapped by Nichols and Wright (1971). These areas were all vegetated by nearly pure mats of perennial pickleweed. The San Leandro site is located on the eastern shore of San Francisco Bay, just north of Sulfur Creek. Creek runoff is diverted directly into the bay. Tidewaters occasionally breach the dike, and the marsh retains rainwater. There is a small drainage channel, but drainage is slow. The site is believed to have been used as a salt evaporation pond in the 1800's; small salt pans remain in the marsh. Salt operations were apparently abandoned prior to 1930, when aerial photos show the site to be at least partially vegetated (M. Taylor, East Bay Regional Park District; pers. comm.). The Coyote Hills study site is within the Coyote Hills Regional Park, on the east side of San Francisco Bay, just south of the Alameda Creek Flood Control Channel. Reyes soils occurred in a diked marsh in the northeast part of the park. The marsh ponds rainwater, which is peiodically drained by the opening of one-way tide gates (H. Cogswell, pers. comm.) New Chicago marsh is located at the southern tip of San Francisco Bay in Alviso. Subsidence is notable at this site, and the marsh ponds rainwater (R. Coleman, FWS; pers. comm.).

Novato and Joice soils were found in areas receiving regular tidal inundation. Novato soils were most commonly vegetated by salt marsh communities. The Newark Slough sample replication was located on Dumbarton Point. Tidal channels were lined by Pacific cordgrass. Away from channels, perennial pickleweed was dominant, mixed with saltgrass, alkali heath, and fleshy jaumea. In San Leandro Bay (part of San Francisco Bay) Arrowhead marsh occurs as a peninsula that is believed to have been deposited in the late 1800's (Cuneo 1987). This marsh was dominated by fleshy jaumea, with cordgrass and saltgrass.

[1] See Tiner (1985) for a discussion of the characteristics associated with hydric soils.

Table 1. Location of San Francisco Bay estuary study sites.

County	Quadrangle	Site	Replication number	Township, range, section		
Marin	Petaluma Point	China Camp	1	T2N	R6W	NE1/4 of NE1/4, Sec. 23
			2,3	T2N	R6W	SE1/4 of NW1/4, Sec. 23
			4,5	T2N	R6W	SW1/4 of NE1/4, Sec. 23
Solano	Benicia	Southampton Bay	6	T3N	R3W	SE1/4 of SE1/4, Sec. 28
	Fairfield South	Hill Slough	7	T4N	R1W	NW1/4 of NW1/4, Sec. 6
			8,9	T5N	R1W	SE1/4 of NW1/4, Sec. 31
			10,11	T5N	R1W	SW1/4 of NW1/4, Sec. 31
	Denverton	Montezuma Slough	12	T4N	R1W	SW1/4 of SW1/4, Sec. 16
			13	T4N	R1W	NE1/4 of SE1/4, Sec. 17
			14	T4N	R1W	NE1/4 of SW1/4, Sec. 16
			15	T4N	R1W	NW1/4 of SW1/4, Sec. 16
			16	T4N	R1W	SE1/4 of NE1/4, Sec. 17
			17	T4N	R1W	SW1/4 of NE1/4, Sec. 17
Contra Costa	Benicia	Martinez	18	T2N	R3W	NE1/4 of NE1/4, Sec. 13
Alameda	San Leandro	Arrowhead marsh	19	T2S	R3W	SE1/4 of NE1/4, Sec. 20
		San Leandro	20	T3S	R3W	NE1/4 of NE1/4, Sec. 23
			21	T3S	R3W	SE1/4 of NE1/4, Sec. 23
	Newark	Coyote Hills	22	T4S	R2W	NE1/4 of NW1/4, Sec. 28
			23	T4S	R2W	SE1/4 of NE1/4, Sec. 28
			24	T4S	R2W	NE1/4 of SE1/4, Sec. 28
			25,26	T4S	R2W	NW1/4 of SE1/4, Sec. 28
			27,28	T4S	R2W	SE1/4 of NW1/4, Sec. 28
		Newark Slough	29	T5S	R2W	SE1/4 of SW1/4, Sec. 9
			30	T5S	R2W	SW1/4 of NE1/4, Sec. 3
			31	T5S	R2W	SE1/4 of NW1/4, Sec. 3
	Milpitas	Fremont	32,33	T5S	R1W	SE1/4 of NE1/4, Sec. 21
			34,35	T5S	R1W	NE1/4 of SE1/4, Sec. 21
Santa Clara	Milpitas	New Chicago marsh	36	T6S	R1W	SE1/4 of SW1/4, Sec. 3

Table 2. Management and land use of San Francisco Bay estuary study sites.

Site	Management	Land use
China Camp	California Department Parks and Recreation	Recreation
Southampton Bay	California Department Parks and Recreation	Recreation
Hill Slough	California Department Fish and Game	Game refuge
Montezuma Slough	California Department Fish and Game	Game refuge
Martinez	East Bay Regional Park District	Recreation
Arrowhead marsh	East Bay Regional Park District	Recreation
San Leandro	East Bay Regional Park District	Recreation
Coyote Hills	East Bay Regional Park District	Recreation
Newark Slough	U.S. Fish and Wildlife Service	Recreation/ Refuge
Fremont	Private	Cattle grazing
New Chicago marsh	U.S. Fish and Wildlife Service	Recreation

China Camp, on the southwestern shore of San Pablo Bay, was the site of a Chinese fishing village in the late 1800's. The area has been a State park since 1977, and is now used for recreation. Tidal marsh occurs as a fringe along the shore, bordered by hills. Pacific cordgrass was found in a narrow band along the water's edge; the rest of the marsh was dominated by perennial pickleweed. The final site where Novato soils were sampled was at Martinez, located on the south side of Carquinez Strait. The brackish species California bulrush and narrow-leaved cattail were found at Martinez, which receives freshwater inflow from the Sacramento-San Joaquin Delta.

Joice soils were sampled at three different study sites. The tidal marsh at Southampton Bay, on the north side of Carquinez Strait, is part of the Benicia State Recreation Area. The marsh was largely perennial pickleweed, with bulrushes and cattails occurring at the upper margins and along tidal channels. Hill Slough is located in Suisun Marsh, on the north side of Suisun Bay. This tidal marsh was dominated by Olney's bulrush, with hardstem bulrush (*Scirpus acutus*), baltic rush, and silverweed (*Potentilla anserina* ssp. *egedii*). The last two Joice replications were in sites bordering Montezuma Slough, near Hill Slough. These marshes were vegetated by perennial pickleweed, saltgrass, and baltic rush, with Olney's bulrush at the water's edge.

Omni soils were sampled at Coyote Hills Regional Park. These areas occur just along the border of the historic baylands margin, as mapped by Nichols and Wright (1971). The historic hydrologic regime is unclear. Now the areas are seasonal wetlands: they pond rainwater, which is periodically drained by the opening of one-way tidegates (H. Cogswell, pers. comm.). The site of the first sample replication, a nearly pure stand of perennial pickleweed, was notably more saline than the other three sites. When new dikes were constructed in the early 1960's, the old dikes were first destroyed. This allowed a brief period of tidal inundation, which presumably increased salinity levels in this area (H. Cogswell, pers. comm.). The other replications were in sites where barley was farmed prior to 1968, when the land was acquired by the East Bay Regional Park District (H. Cogswell, pers. comm.). These areas were vegetated by a mixture of perennial pickleweed, alkali heath, alkali bulrush, perennial ryegrass (*Lolium perenne* var. *perenne*), and rabbitfoot grass (*Polypogon monspeliensis*).

Table 3. Soil type, FWS wetland classification, and hydrological conditions for each sample replication. Soil series were determined in the field by SCS soil scientists. Discrepancies between these soil determinations and published maps (SCS 1941, 1977a, 1977b, 1981, 1985d) are noted. Soils determined as hydric are marked with an asterisk. FWS wetland classifications were taken from National Wetlands Inventory Maps (USFWS 1985) for these areas. Descriptions of hydrology were based on personal observation and personal communication.

Soil series & texture	Site	Replication number	FWS wetland classification[a]	Hydrology
* Reyes clay [b]	San Leandro	20	PEMCh	Seasonal ponding
* Reyes clay [b]	San Leandro	21	PEMCh	Seasonal ponding
* Reyes clay [b]	Coyote Hills	22	E2EMPh	Seasonal ponding
* Reyes clay [c]	New Chicago marsh	36	PEMCh	Seasonal ponding
* Novato clay	China Camp	1	E2EMN	Regular tidal inundation
* Novato clay [d]	Martinez	18	E2EMN	Regular tidal inundation
* Novato clay [e]	Arrowhead marsh	19	E2EMN	Regular tidal inundation
* Novato clay [e]	Newark Slough	29	E2EMN	Regular tidal inundation
* Joice muck	Southampton Bay	6	E2EMN	Regular tidal inundation
* Joice muck	Hill Slough	7	E2EMN	Regular tidal inundation
* Joice muck	Montezuma Slough	12	E2EMN	Regular tidal inundation
* Joice muck	Montezuma Slough	13	E2EMN	Regular tidal inundation
* Omni silty clay loam [f]	Coyote Hills	23	PEMCh	Seasonal ponding
* Omni silty clay loam [g]	Coyote Hills	24	PEMCh	Seasonal ponding
* Omni silty clay loam [g]	Coyote Hills	25	PEMCh	Seasonal ponding
* Omni silty clay loam [g]	Coyote Hills	26	PEMCh	Seasonal ponding
* Pescadero clay [g]	Fremont	32	PEMA	Seasonal ponding
* Pescadero clay [g]	Fremont	33	PEMA	Seasonal ponding
* Pescadero clay [g]	Fremont	34	PEMA	Seasonal ponding
* Pescadero clay [g]	Fremont	35	PEMA	Seasonal ponding
* Alviso silty clay loam	Hill Slough	8	Pf	Seasonal ponding
* Alviso silty clay loam	Hill Slough	9	Pf	Seasonal ponding
* Alviso silty clay loam	Hill Slough	10	Pf	Seasonal ponding
* Alviso silty clay loam	Hill Slough	11	Pf	Seasonal ponding

(Continued)

Table 3. (Concluded)

Soil series & texture	Site	Replication number	FWS wetland classification[a]	Hydrology
Antioch loam [h]	Montezuma Slough	14	Upland	Upland
Antioch loam [h]	Montezuma Slough	15	Upland	Upland
Antioch loam [h]	Montezuma Slough	16	Upland	Upland
Antioch loam [h]	Montezuma Slough	17	Upland	Upland
Ballard gravelly loam [i]	China Camp	2	Upland	Upland
Ballard gravelly loam [i]	China Camp	3	Upland	Upland
Ballard gravelly loam [i]	China Camp	4	Upland	Upland
Ballard gravelly loam [i]	China Camp	5	Upland	Upland
Vallecitos gravelly loam [j]	Coyote Hills	27	Upland	Upland
Vallecitos gravelly loam [j]	Coyote Hills	28	Upland	Upland
Vallecitos gravelly loam [j]	Newark Slough	30	Upland	Upland
Vallecitos gravelly loam [j]	Newark Slough	31	Upland	Upland

[a]Terminlogy follows the FWS wetland classification system (Cowardin et al. 1979). Definition of wetland classifications shown above:

		System	Subsystem	Class	Water regime	Modifier
E2EMN	=	Estuarine (E)	intertidal (2)	emergent wetland (EM)	regularly flooded (N)	
E2EMPh	=	Estuarine (E)	intertidal (2)	emergent wetland (EM)	irregularly flooded (P)	diked (h)
PEMA	=	Palustrine (P)	--	emergent wetland (EM)	temporarily flooded (A)	
PEMCh	=	Palustrine (P)	--	emergent wetland (EM)	seasonally flooded (C)	diked (h)
Pf	=	Palustrine (P)	--	--	--	farmed (f)

b Mapped as "Reyes clay, drained" (SCS 1981). See text for SCS 1985 redefinition of Reyes.
c Mapped as "Tidal marsh" (SCS 1941).
d Mapped as "Reyes silty clay" (SCS 1977a). See text for distinction between Reyes and Novato.
e Mapped as "Reyes clay" (SCS 1981). See text for distinction between Reyes and Novato.
f Soil phase: "stongly saline" (SCS 1981). See text for site history.
g Soil phase: "drained" (SCS 1981). See text for site history.
h Included in the mapping unit "Antioch-San Ysidro complex, 0%-2% slopes" (SCS 1977b).
i Mapped as "Tocaloma-McMullin complex,50%-75% slopes" (SCS 1985d). See text for explanation.
j Included in the mapping unit "Vallecitos-Rock outcrop complex, 30%-50% slopes" (SCS 1981).

Pescadero soils were sampled at a Fremont site that lies just outside the historic baylands margin, as mapped by the Nichols and Wright (1971). Adjacent areas to the south that were within the historic baylands margin are now managed as salt evaporation ponds. Soils sampled at the site had a hard, impervious surface, which is characteristic of the Pescadero series (D. White, SCS; pers. comm.) The topography of the site is undulating, and rainwater ponds at lower elevations. The site is used for cattle grazing. Salt pans were found on the site, some devoid of vegetation, others with sparse colonization by annual pickleweed (*Salicornia europea*). Various mixtures of saltgrass, alkali heath and perennial pickleweed were found, with Mediterranean barley (*Hordeum geniculatum*), soft chess (*Bromus mollis*), and perennial ryegrass occurring on higher spots.

Alviso soils were sampled near Hill Slough, in a diked area adjacent to the tidal marsh described for Joice soils. The site occurs within the historic baylands margin, as mapped by Nichols and Wright (1971). Alviso soils are described by the SCS (1977b) as occurring on the rims of marshes, with typical vegetation consisting of pickleweed and salt-tolerant grasses. The site where Alviso soils were sampled has been diked for at least the past 40 years. Cattle were grazed on the site prior to 1979, when the land was acquired by the California Department of Fish and Game. In 1983, barley was planted in this area to provide waterfowl food. The site ponds water in the winter, and drainage (through pipes) occurs slowly (D. Becker, Calif. Dept. Fish Game; pers. comm.). The site was dominated by perennial ryegrass, with Mediterranean barley, alkali heath, and prickly lettuce (*Lactuca serriola)*.

Antioch soils were found in upland near Montezuma Slough, adjacent to the tidal marsh described as a sample site for Joice soils. The transition from marsh to upland was a gentle slope. The soils map unit described for this upland area is the Antioch-San Ysidro complex, 0%-2% slopes (SCS 1977b). The soils on which vegetation was sampled were determined in the field to belong to the Antioch component of this complex. Sample sites were dominated by ripgut grass (*Bromus diandrus*), mixed with perennial ryegrass, Mediterranean barley, and soft chess.

Ballard soils were found in alluvial fans at the base of hills at China Camp, adjacent to the tidal marsh described as a sample site for Novato soils. The Marin County soil survey (SCS 1985d) described the predominant soils of the hills here as the Tocaloma-McMullin complex, 50%-75% slopes, map unit; the survey did not delineate the occurrence of Ballard soils along the base of the hills. The Ballard soil series determination was made on-site by SCS soil scientist Donald White. Ballard soils were vegetated by ripgut grass and wild oats (*Avena fatua*), with scattered coyote bush (*Baccharis pilularis* ssp. *consanguinea*), Garry oak (*Quercus garryana*), California buckeye (*Aesculus californica*), and tree of heaven (*Ailanthus altissima*).

Vallecitos soils were found on steep slopes in the Coyote Hills, adjacent to tidal marsh. Vallecitos soils occurred as part of the Vallecitos-Rock outcrop complex, 30%-50% slopes, map unit, with rock outcrop covering about 20% of the slopes (SCS 1981). Two of the replications were sampled near Newark Slough, on hills where the San Francisco Bay National Wildlife Refuge visitor's center is located. The other two replications were located at Coyote Hills Regional Park. Vallecitos soils were vegetated by ripgut grass, wild oats, California sagebrush (*Artemisia californica*), buckwheat (*Eriogonum nudum* var. *nudum*), and soap plant (*Chlorogalum pomeridianum*).

VEGETATION SAMPLING

Four sets of vegetation samples were collected as replications for each soil series. When possible, these sample sets, or replications, were located at different sites; otherwise they were situated in different areas within the same site. Vegetation was sampled by stratum. Each sample set consisted of 25 plots, including 10 plots (0.5 m^2) for the ground cover or herbaceous stratum, 5 plots (4 m^2) for the short shrub

stratum, 5 plots (4 m2) for the tall shrub stratum, and 5 plots (100 m^2) for the tree stratum (Table 4). The means of estimating a species' abundance, or its 'importance value,' varied by vegetation stratum. For the ground cover stratum, species importance values were measured in terms of percent cover, using Daubenmire's (1968) system of 6 cover classes (Table 5). Species importance values were measured in terms of density for the short shrub, tall shrub, and tree strata (Table 4). Within each sample set, location of the first ground cover plot was randomly selected using a point-coordinate system and random numbers table (Daubenmire 1968). Subsequent ground cover plots were placed along a transect at intervals of 10 m. When present, short shrub, tall shrub, and tree strata were sampled in plots centered around the ground cover transect.

Table 4. Vegetation sampling specifications by stratum. Four sample sets, or replications, were sampled for each soil series. "N" represents the number of sample plots per replication.

Vegetation stratum	Definition	Importance value measured	Plot size	N
Ground cover	All herbaceous spp., and woody spp. < 0.5 m tall	% Cover (classes 1-6)	0.5 m^2	10
Short shrubs	Woody spp. ≥ 0.5 m and < 1.3 m tall	Density (no. individuals)	4 m^2	5
Tall shrubs	Woody spp. ≥ 1.3 m tall and with dbh < 7.5 cm	Density (no. main leaders)	4 m^2	5
Trees	Woody spp. with dbh ≥ 7.5 cm	Density (no. main leaders)	100 m^2	5

Table 5. Daubenmire (1968) cover classes used to measure the ground cover stratum.

Cover class	Range (% cover)	Midpoint (% cover)
1	0 - 5	2.5
2	6 - 25	15.0
3	26 - 50	37.5
4	51 - 75	62.5
5	76 - 95	85.0
6	96 -100	98.0

ANALYSIS

Each plant species was assigned a wetland indicator status, based on the FWS wetland plant list for the California region (Reed 1986) (Table 6 and Appendix C). The wetland plant list categorizes plant species according to their frequency of occurrence in wetlands within particular regions. Under natural conditions, obligate species are more or less restricted to wetland habitats. Facultative wetland species usually occur in wetlands, but occasionally can be found in uplands. Facultative species are tolerant of both wet and dry environments, and do not demonstrate a strong preference for either. Facultative upland species usually occur in uplands, but occasionally can be found in wetlands. Drawdown species are typically associated with the drier stages of wetlands, such as mudflats, vernal pools, and playa lakes. Nonwetland, or upland, species are more or less restricted to upland habitats, but may occur in wetlands in a different region. If a species is not known to occur in wetlands in any region, it is not on the FWS wetland plant list (Reed 1986).

For calculation purposes, each wetland indicator category was represented by an index number. Two types of index scale were tried in the analyses for comparison. The simpler of the two, the 'ecological index' scale, consists of integers 1-5 for the 5 wetand indicator categories obligate-upland (Table 6). The units on this scale are all of equal proportion (i.e., each unit has a magnitude of 1). Reed's (1986) frequency of occurrence ranges for the 5 wetland categories, however, are not of equal proportion (i.e., the obligate and upland categories represent smaller frequency ranges than the other categories). The second index scale used, the 'frequency midpoint index' scale, is in proportion to the percent frequency ranges of Reed's (1986) wetland indicator categories (Table 6). The index is based on the midpoints of the percent frequency ranges, in a modification of a technique used by Michener (1983).The frequency midpoint index differs from the ecological index by giving facultative wetland species a value closer to the wetland end of the scale (i.e.,1.67 rather than 2) and giving facultative upland species a value closer to the upland end of the scale (i.e., 4.33 rather than 4). Both index scales are actually based on a reversed definition of the categories, with the percent frequency ranges reversed to represent frequency of occurrence in uplands rather than in wetlands. That is why the index numbers are smaller at the wetland end of the scale than at the upland end.

Table 6. Wetland indicator categories for plant species, defined by frequency of occurrence in wetlands (Reed 1986). The ecological index number and frequency midpoint index number assigned to each category is also shown.

Wetland indicator category	Abbreviation	Frequency of occurrence in wetlands	Ecological index	Frequency midpoint index
Obligate	OBL	> 99 %	1	1.00
Facultative wetland	FACW	67 % - 99 %	2	1.67
Facultative	FAC	34 % - 66 %	3	3.00
Facultative upland	FACU	1 % - 33 %	4	4.33
Nonwetland (upland)	UPL	< 1 %	5	5.00
Drawdown[a]	DRA	–	–	–

[a]The modifier 'drawdown' is used in combination with another wetland indicator category. Drawdown species were assigned the index number of the category describing their occurrence in wetlands.

Plant species index numbers were used to compute a score for each sample plot indicating the plot's position on the wetland-upland gradient. Two different methods of computing plot scores were tried for comparison, following Wentworth and Johnson (1986). The two methods used were the 'weighted average' and 'index average' methods. The weighted average (WA) method incorporates species importance values (Tables 4 and 5) into the calculation, such that dominant species are given more weight than minor species (Table 7). The WA algorithm is:

$$WA_j = \left(\sum_{i=1}^{p} I_{ij} E_i\right) + \left(\sum_{i=1}^{p} I_{ij}\right) \qquad (1)$$

where: WA_j = weighted average for plot j
I_{ij} = importance value of species i in plot j
E_i = ecological index for species i
p = number of species in plot j

The index average (INAV) method uses only species presence/absence data, giving all species equal weight in the calculation of a plot score (Table 8). The weighted average algorithm (1) is modified as:

$$INAV_j = \left(\sum_{i=1}^{p} E_i\right) + p \qquad (2)$$

where: $INAV_j$ = index average for plot j

Table 7. Sample calculation of a weighted average (WA) score. Data were collected in tidal marsh at the China Camp study site (Novato soil series, replication 1, ground cover stratum, plot 10). The importance values shown here are the midpoints of cover classes recorded in the field.

Plant species	Importance value (I) (% cover)	Ecological index (E)	Product (I x E)
Salicornia virginica	62.5	1	62.5
Distichlis spicata	15.0	2	30.0
Frankenia grandifolia	15.0	2	30.0
Jaumea carnosa	2.5	1	2.5
	------		-----
	sum = 95.0		sum = 125.0

WA = sum of products + sum of importance values
= 125.0 + 95.0 = 1.32

Table 8. Sample calculation of an index average (INAV) score. Plot data are the same as shown in Table 7.

Plant species	Ecological index (E)
Salicornia virginica	1
Distichlis spicata	2
Frankenia grandifolia	2
Jaumea carnosa	1
-----------------------	–
total number of species = 4	sum = 6

INAV = sum of index values ÷ total number of species
= 6 ÷ 4 = 1.50

Four types of score were computed for each sample plot, including (1) a WA score based on the ecological index, (2) an INAV score based on the ecological index, (3) a WA score based on the frequency midpoint index, and (4) an INAV score based on the frequency midpoint index. Four mean scores were then derived for each set of sample plots (i.e., each replication), and for each soil series, by vegetation stratum. Pearson's product moment correlation coefficients were calculated to determine how closely the results of these various methods of analysis agreed with one another.

Following Bartlett's test for homogeneity of variance, a one-way analysis of variance (ANOVA) was performed to determine whether soil series differed significantly from one another in their WA and INAV scores. A Duncan's Multiple Range Test was performed to assess which soils were significantly different. The computer program package SYSTAT (Wilkinson 1986) was used for all statistical computations.

RESULTS

Most of the vegetation at the study sites occurred as ground cover stratum (Table 9). The scientific names and common names of all species sampled are listed in Appendix C. Salt marshes were vegetated primarily by low-growing succulents and grasses. Brackish marshes were dominated by bulrushes and cattails, which, though tall, were measured as ground cover, since they are herbaceous (Table 4). Diked former tidelands were vegetated by mats of pickleweed. Other seasonal wetlands sampled had mixtures of pickleweed, annual grasses, and drawdown species. Uplands adjacent to wetlands were generally grassland. Shrubs and trees occurred in sufficient density for sampling on only one soil series (Ballard), found on hillsides adjacent to tidal marsh, at the China Camp study site. All shrub and tree species on Ballard were upland species, therefore WA and INAV scores computed for these strata all equaled 5.00. All other WA and INAV scores presented here were based on ground cover stratum data.

About 38% of the 93 plant species sampled were restricted to hydric soils and 42% of the species were restricted to nonhydric soils. The remaining 20% of the species were found on both hydric and nonhydric soils, though rarely with equal frequency (Table 9). Those species occurring on both hydric and nonydric soils included representatives from all wetland indicator categories, OBL through UPL (or, ecological index numbers 1-5) (Table 9). Generally, the lower the index number, the more likely a plant species was to be restricted to hydric soils. Likewise, the higher the index number, the greater the tendency to be restricted to nonhydric soils. Of the 25 OBL (E=1) plant species sampled, 92% were found only on hydric soils and 8% were found on both hydric and nonhydric soils. Of the 14 FACW (E=2) plant species sampled, 50% were found only on hydric soils, 36% were found on both hydric and nonhydric soils, and 14% were found only on nonhydric soils. Of the 16 FAC (E=3) plant species sampled, 25% were found only on hydric soils, 25% were found on both hydric and nonhydric soils, and 50% were found only on nonhydric soils. Of the 3 FACU (E=4) plant species sampled, 33% were found on both hydric and nonhydric soils and 67% were found only on nonhydric soils. Of the 35 UPL (E=5) plant species sampled, 3% were found only on hydric soils, 20% were found on both hydric and nonhydric soils, and 77% were found only on nonhydric soils (Table 9).

Hydric soil types were vegetated primarily by plant species belonging to the OBL, FACW, and FAC wetland indicator categories. Nonhydric soils were vegetated primarily by plant species belonging to the UPL wetland indicator category. This pattern was evident both in terms of the number of species belonging to each category (Table 10), and in terms of coverage by species belonging to each category (Table 11). The percentage of species belonging to the OBL, FACW, and FAC wetland indicator categories combined was > 50% for each hydric soil and < 50% for each nonhydric soil. Similarily, the percent coverage by species belonging to the OBL, FACW, and FAC wetland indicator categories combined was > 50% for each hydric soil and < 50% for each nonhydric soil.

The ecological index scale and the frequency midpoint index scale produced very similar results, both in the computation of WA scores (Pearson's product moment correlation coefficient=0.998, N=360), and in the computation of INAV scores (Pearson's correlation coefficient=0.999, N=360). Only the WA and INAV scores computed using the ecological index scale are presented (Tables 12-14).

There was a high correlation between scores computed by the WA method and those computed by the INAV method, both when using the ecological index (Pearson's correlation coefficient=0.961, N=360), and when using the frequency midpoint index (Pearson's correlation coefficient=0.959, N=360).

Table 9. Percent frequency of occurrence for plant species on nine soil series in the San Francisco Bay estuary area, listed by vegetation stratum. Percent frequency values are based on N = 40 sample plots (0.5 m^2) per soil series for the ground cover stratum, N = 20 sample plots (4 m^2) per soil series for the short shrub and tall shrub strata, and N = 20 sample plots (100 m^2) for the tree stratum. The ecological index number (E) assigned to each plant species is shown. Each 'E' corresponds to an estimated range of frequency of occurrence in wetlands, as defined in Table 6. Soil series names are abbreviated as follows: Rey=Reyes, Nov=Novato, Joi=Joice, Om=Omni, Pes=Pescadero, Alv=Alviso, Ant=Antioch, Bal=Ballard, and Val=Vallecitos.

		Hydric soils						Nonhydric soils		
E	Plant species	Rey	Nov	Joi	Om	Pes	Alv	Ant	Bal	Val
	Ground cover stratum									
1	*Salicornia virginica*	100	60	68	95	23				
1	*Spergularia marina*	3								
1	*Spartina foliosa*		38							
1	*Jaumea carnosa*		35	10						
2	*Distichlis spicata* var. *stolonifera*		33	55		30	18	20		3
2	*Grindelia humilis*		15	5						
1	*Scirpus californicus*		13							
1	*Typha angustifolia*		10	3						
1	*Triglochin maritimum*		10	10						
1	*Cuscuta salina* var. *major*		3	15						
1	*Juncus balticus*			45					5	
1	*Scirpus americanus*			30						
1	*Potentilla anserina* ssp. *egedii*			25						
1	*Polypogon interruptus*			15						
1	*Oenanthe sarmentosa*			15						
1	*Polygonum hydropiperoides*			10						
1	*Scirpus acutus*			5						
1	*Glaux maritima*			5						
1	*Hydrocotyle verticillata* var. *triradiata*			5						
2	*Lepidium latifolium*			5						
2	*Plantago hirtella* var. *galeottiana*			5						
1	*Scirpus cernuus*			3						
1	*Helenium bigelovii*			3						
1	*Calystegia sepium* ssp. *limnophila*			3						
3	*Polypogon monspeliensis*	5		18	73					
2	*Atriplex patula*			15	35		3			
2	*Cotula coronopifolia*	8		10	8	13				
3	*Lotus corniculatus*			8	3					
2	*Frankenia grandifolia*	5	15		40	63	45	15		3
5	*Medicago polymorpha*				40					3
3	*Hemizonia pungens* ssp. *maritima*				33	18				
1	*Scirpus robustus*		3		30					
2	*Rumex crispus*				30		3		18	

(Continued)

Table 9. (Continued)

E	Plant species	Hydric soils: Rey	Nov	Joi	Om	Pes	Alv	Nonhydric soils: Ant	Bal	Val
3	*Melilotus indica*				10					8
3	*Malvella leprosa*				5					
1	*Heliotropium curassavicum* var. *oculatum*				5	3		3		
3	*Hordeum geniculatum*				5	83	55	38	23	
4	*Bromus mollis*				3	73	3	60	75	33
3	*Lolium perenne* var. *perenne*				18	65	88	63	85	15
2	*Vulpia bromoides*					18		3	30	
1	*Salicornia europaea*					10				
1	*Eryngium aristulatum*					10				
2	*Monerma cylindrica*					8				
2	*Plantago elongata*					5				
1	*Lepidium oycarpum*					3				
2	*Vulpia myuros* var. *hirsuta*					3				18
5	*Erodium cicutarium*					8		3	5	
3	*Lactuca serriola*						65	50	3	
5	*Hordeum leporinum*						23	50	8	10
5	*Brassica nigra*						8			
5	*Bromus diandrus*					3		90	70	83
5	*Convolvulus arvensis*							40	15	5
3	*Elymus triticoides* ssp. *triticoides*							13		
5	*Epilobium brachycarpum*				3			5		
2	*Cressa truxillensis*							5		5
5	*Taeniatherum caput-medusae*							3		
5	*Geranium* sp.							3		
3	*Iva axillaris*							3		
5	*Avena fatua*					15		5	83	88
5	*Avena barbata*								43	8
3	*Plantago lanceolata*								25	
5	*Carduus pycnocephalus*							3	18	
5	*Cynosurus echinatus*								18	
5	*Briza maima*								10	
4	*Vicia sativa*								10	
5	*Aira caryophyllea*								8	
3	*Rosa californica*								5	
5	*Torilis arvensis*								5	
2	*Artemisia douglasiana*								3	
3	*Rumex acetosella*								3	
3	*Aquilegia formosa*								3	
3	*Sisyrinchium bellum*								3	
4	*Elymus glaucus* var. *jepsonii*								3	
5	*Quercus garryana*								3	
5	*Vicia villosa*								3	
5	*Toxicodendron diversilobum*								3	

(Continued)

Table 9. (Concluded)

E	Plant species	Hydric soils						Nonhydric soils		
		Rey	Nov	Joi	Om	Pes	Alv	Ant	Bal	Val
5	*Eriogonum nudum* var. *nudum*									58
5	*Artemisia californica*									25
5	*Chlorogalum pomeridianum*									23
5	*Bromus rubens*									20
5	*Stipa pulchra*								8	18
5	*Brassica campestris*									13
5	*Silene gallica*					3				13
5	*Hypochaeris glabra*								5	10
5	*Centaurea melitensis*									8
5	*Eschscholzia californica*									5
5	*Lupinus* sp.									3
3	*Atriplex semibaccata*									3
5	*Melica californica*									3
	Short shrub stratum									
5	*Baccharis pilularis* ssp. *consanguinea*								10	
5	*Mimulus aurantiacus*								5	
	Tall shrub stratum									
5	*Baccharis pilularis* ssp. *consanguinea*								10	
	Tree stratum									
5	*Ailanthus altissima*								15	
5	*Aesculus californica*								5	
5	*Quercus garryana*								5	

The results of ANOVA indicated that the differences among soil series' scores (both WA and INAV) were significant at the $p < 0.0001$ level. (Assumptions of normality were met, based on Bartlett's test.) The results of Duncan's Multiple Range Test suggested that most of the soil series differed significantly from all others in their WA and INAV scores at $p < 0.05$ (Tables 12 and 13). Reyes and Novato were an exception. This pair of soil series showed no significant difference between either their WA or INAV means. In addition, no significant difference was found between the WA means of Novato and Joice (Table 12).

The order in which soil series were ranked from lowest to highest score was the same for WA and INAV results. The hydric soil types sampled all produced WA and INAV means below 3.00, and the nonhydric soil types all produced WA and INAV means above 3.00 (Tables 12 and 13).

The variation in WA and INAV scores among replications within each soil series is shown in Table 14. Of the 60 replications sampled on hydric soils, all but one produced WA and INAV means below 3.0. The exception was on the Alviso soil series at the Hill Slough site, replication 9, which had a WA mean of 3.13 ± 0.12, and an INAV mean of 3.27 ± 0.14. The 30 replications sampled on nonhydric soils all produced WA and INAV means above 3.0 (Table 14).

Table 10. Percentage of total plant species belonging to each wetland indicator category, listed by soil series. Hydric soils are marked with an asterisk. Wetland indicator categories: OBL=Obligate, FACW=Facultative wetland, FAC=Facultative, FACU=Facultative upland, UPL=upland.

Soil series	Total # species	Percentage of plant species					Total % species
		OBL	FACW	FAC	FACU	UPL	
* Reyes	5	40.0	40.0	20.0			100
* Novato	11	72.7	27.3				100
* Joice	25	68.0	24.0	8.0			100
* Omni	17	17.6	23.5	41.2	5.9	11.8	100
* Pescadero	20	25.0	35.0	15.0	5.0	20.0	100
* Alviso	10		40.0	30.0	10.0	20.0	100
Antioch	20	5.0	15.0	25.0	5.0	50.0	100
Ballard	35	2.9	8.6	22.8	8.6	57.1	100
Vallecitos	26		15.4	11.5	3.9	69.2	100

Table 11. Percentage of total cover for plant species belonging to each wetland indicator category, listed by soil series. Hydric soils are marked with an asterisk. Wetland indicator categories: OBL=Obligate, FACW=Facultative wetland, FAC=Facultative, FACU=Facultative upland, UPL=upland.

Soil series	Percentage cover					Total % cover
	OBL	FACW	FAC	FACU	UPL	
* Reyes	99.3	0.3	0.4			100
* Novato	77.6	22.4				100
* Joice	76.5	21.7	1.8			100
* Omni	59.6	15.1	24.0	0.1	1.2	100
* Pescadero	16.8	34.1	27.3	19.4	2.4	100
* Alviso		25.9	70.8	0.1	3.2	100
Antioch	0.1	5.9	33.2	11.1	49.7	100
Ballard	0.8	3.5	19.6	11.4	64.7	100
Vallecitos		7.6	1.8	2.4	88.2	100

Table 12. Weighted average scores by soil series, based on ground cover stratum data. Hydric soils are marked with an asterisk. Also shown are the results of Duncan's Multiple Range Test: means sharing the same letter designation are not significantly different from one another at $p < 0.05$.

Soil series	Duncan's test	Weighted average mean ± std error	Weighted average minimum	Weighted average maximum	N
* Reyes	A	1.01 ± 0.01	1.00	1.17	40
* Novato	A B	1.21 ± 0.06	1.00	1.98	40
* Joice	B	1.23 ± 0.04	1.00	1.56	40
* Omni	C	1.53 ± 0.07	1.00	2.59	40
* Pescadero	D	2.59 ± 0.11	1.00	4.03	40
* Alviso	E	2.81 ± 0.06	2.14	4.24	40
Antioch	F	4.10 ± 0.11	2.80	5.00	40
Ballard	G	4.31 ± 0.10	2.81	5.00	40
Vallecitos	H	4.73 ± 0.08	2.73	5.00	40

Table 13. Index average scores by soil series, based on ground cover stratum data. Hydric soils are marked with an asterisk. Also shown are the results of Duncan's Multiple Range Test: means sharing the same letter designation are not significantly different from one another at $p < 0.05$.

Soil series	Duncan's test	Index average mean ± std error	Index average minimum	Index average maximum	N
* Reyes	A	1.06 ± 0.03	1.00	1.67	40
* Novato	A	1.19 ± 0.04	1.00	1.67	40
* Joice	B	1.29 ± 0.04	1.00	1.67	40
* Omni	C	1.94 ± 0.09	1.00	3.00	40
* Pescadero	D	2.67 ± 0.10	1.00	3.67	40
* Alviso	E	2.99 ± 0.06	2.50	4.00	40
Antioch	F	3.95 ± 0.08	3.00	5.00	40
Ballard	G	4.16 ± 0.08	3.00	5.00	40
Vallecitos	H	4.67 ± 0.06	3.20	5.00	40

Table 14. Weighted average (WA) and index average (IA) means ± standard error, listed by replication.

Soil series	Site	Replication	WA mean	IA mean	N
Reyes	San Leandro	20	1.00 ± 0.00	1.00 ± 0.00	10
	San Leandro	21	1.00 ± 0.00	1.05 ± 0.05	10
	Coyote Hills	22	1.00 ± 0.00	1.00 ± 0.00	10
	New Chicago marsh	36	1.03 ± 0.02	1.18 ± 0.09	10
Novato	China Camp	1	1.05 ± 0.03	1.10 ± 0.07	10
	Martinez	18	1.08 ± 0.05	1.12 ± 0.06	10
	Arrowhead marsh	19	1.18 ± 0.11	1.16 ± 0.05	10
	Newark Slough	29	1.54 ± 0.14	1.39 ± 0.09	10
Joice	Southampton Bay	6	1.28 ± 0.09	1.25 ± 0.07	10
	Hill Slough	7	1.16 ± 0.06	1.27 ± 0.09	10
	Montezuma Slough	12	1.31 ± 0.11	1.35 ± 0.09	10
	Montezuma Slough	13	1.18 ± 0.08	1.27 ± 0.06	10
Omni	Coyote Hills	23	1.03 ± 0.02	1.15 ± 0.08	10
	Coyote Hills	24	1.83 ± 0.13	2.37 ± 0.11	10
	Coyote Hills	25	1.67 ± 0.13	2.23 ± 0.11	10
	Coyote Hills	26	1.59 ± 0.09	2.04 ± 0.14	10
Pescadero	Fremont	32	2.27 ± 0.12	2.41 ± 0.04	10
	Fremont	33	2.51 ± 0.06	2.77 ± 0.07	10
	Fremont	34	2.75 ± 0.30	2.74 ± 0.31	10
	Fremont	35	2.81 ± 0.27	2.74 ± 0.22	10
Alviso	Hill Slough	8	2.98 ± 0.02	2.92 ± 0.06	10
	Hill Slough	9	3.13 ± 0.12	3.27 ± 0.14	10
	Hill Slough	10	2.41 ± 0.06	2.84 ± 0.10	10
	Hill Slough	11	2.70 ± 0.11	2.94 ± 0.10	10
Antioch	Montezuma Slough	14	4.84 ± 0.06	4.34 ± 0.16	10
	Montezuma Slough	15	4.22 ± 0.19	4.14 ± 0.12	10
	Montezuma Slough	16	3.89 ± 0.17	3.73 ± 0.14	10
	Montezuma Slough	17	3.44 ± 0.10	3.58 ± 0.09	10
Ballard	China Camp	2	4.06 ± 0.13	3.82 ± 0.08	10
	China Camp	3	4.57 ± 0.15	4.30 ± 0.11	10
	China Camp	4	4.50 ± 0.22	4.59 ± 0.14	10
	China Camp	5	4.10 ± 0.23	3.92 ± 0.15	10
Vallecitos	Coyote Hills	27	4.67 ± 0.22	4.77 ± 0.07	10
	Coyote Hills	28	4.48 ± 0.18	4.56 ± 0.09	10
	Newark Slough	30	4.82 ± 0.14	4.75 ± 0.10	10
	Newark Slough	31	4.94 ± 0.03	4.60 ± 0.18	10

DISCUSSION

Field tests in tidal wetlands, seasonal wetlands, and bordering upland areas of the San Francisco Bay estuary support the use of weighted average and index average methods of vegetation analysis in the designation of wetlands. The results of WA and INAV vegetation analyses could be correlated with soil and hydrologic characteristics at the study sites. In general, wetter soils produced lower WA and INAV scores. Soils occurring in sites regularly flooded by tides (Novato and Joice) produced scores near 1; soils occurring in seasonally wet sites (Omni, Pescadero, and Alviso) produced scores in the range of 2-3; and soils occurring in adjacent upland sites (Antioch, Ballard, and Vallecitos) produced scores of 4-5. One apparent anomaly to the above pattern was the Reyes soil series, which, though found in seasonally wet sites, consistently produced WA and INAV scores of 1.

Reyes soils are by definition drier than Novato soils. One way of distinguishing between the two series is by the difference in their n values. The 'n value' refers to the percent water content of the soil in relation to the percent content of inorganic clay and humus, under field conditions. The higher the n value, the higher the relative water content. The n value is 0.3-0.7 for Reyes soils and 1.0-1.5 for Novato soils (SCS 1985c). In the field, the n value is approximated by the ease with which a soil can be pressed between the fingers (D. White, pers. comm.) The Reyes soils sampled were notably drier than either Novato or Joice soils, yet the WA and INAV means for Reyes were approximately the same as those for Novato (Reyes means were actually slightly lower than Novato, but by a degree assessed as not significant). In this case, an evaluation of the moisture gradient by WA and INAV techniques was obscured by the salinity gradient. The high salinity associated with these Reyes soils had an overriding influence on plant species composition. Reyes study sites were vegetated by nearly pure stands of perennial pickleweed, one of the few species that can tolerate the high salinities found there. Perennial pickleweed is an obligate species (ecological index = 1); therefore, Reyes soils consistently produced WA and INAV scores near 1. The fact that Reyes soils scored on the wetland end of the scale is consistent with the hydric nature of soils at Reyes sample sites, all of which are seasonally wet. It is only the position of Reyes scores in relation to other hydric soils that is out of place.

Wentworth and Johnson (1986) recommended that a breakpoint of 3.0 in WA and INAV scores be used to separate wetlands from uplands, and they provided guidelines regarding the reliability of such a designation. According to the guidelines, when a WA or INAV score falls between 2.5-3.5, "vegetation data alone are inadequate for designation of [the] site; additional data regarding soils and/or hydrology are mandatory." Likewise, Michener (1983), while supporting the use of vegetation analysis in wetland designation, cautioned against "overzealous application" of such methods in cases scoring near the breakpoint. A breakpoint of 3.0 was suitable for separating the hydric soils from the nonhydric soils sampled, with hydric soil series scoring below 3.0 and nonhydric soils scoring above 3.0. Two soil series, Pescadero and Alviso, scored between 2.5-3.0. The Pescadero and Alviso soils sampled were both hydric, supporting wetland designations at the Fremont and Hill Slough sites. In addition, information available on the hydrology at these sites supports wetland designations. According to the Wentworth and Johnson guidelines, the WA and INAV scores for the sites where Reyes, Novato, Joice, and Omni soils were sampled represent a high probability that these sites are wetland. The hydric nature of the soils and hydrological information for these sites all support wetland designations. The scores for sites where Antioch, Ballard, and Vallecitos were sampled represent a high probability that these areas are upland, which is also supported by soils and hydrologic characteristics.

Vegetation sampling was conducted too late in the season for many drawdown plant species and other annuals. This problem was compounded by the fact that the 1986-1987 season was drier than normal for the San Francisco Bay area. Sampling conducted earlier in the growing season or during a more normal hydrologic year might yield somewhat different results. In transitional and upland areas, an increased abundance of annual grasses might result in slightly higher scores. In seasonally wet areas, lower scores might result from the presence of species that typically grow in the moist soils left by evaporating winter pools. I believe that the conclusions drawn from these analyses are valid despite the seasonality of the sampling.

Two types of index scale were compared in the computation of WA and INAV scores. Theoretically, the frequency midpoint index provides a more precise representation of plant species frequency of occurrence in wetlands; however, use of this scale produced nearly the same results as those computed using the simpler ecological index scale. Therefore, the ecological index scale was favored for ease and speed in calculations. Wentworth and Johnson (1986) found little difference between results using the two scales, and concluded that either scale is acceptable in the calculation of WA's and INAV's.

The WA and INAV methods of vegetation analysis produced very similar results in ranking plots on a wetland-upland gradient. Wentworth and Johnson (1986) and Dick-Peddie et al. (1987) also found the results of WA and INAV techniques to be in close agreement with each other. For routine use, the INAV method may be preferable because presence/absence plant species data is quicker to collect in the field than estimates of plant species coverage or density. In questionable cases, a WA should also be computed for comparison, since the WA calculation incorporates a more complete ecological representation of the vegetation than does the INAV calculation.

By definition, hydric soils are associated with hydrophytic vegetation, and both reflect the hydrologic conditions that make a wetland a wetland. But sometimes hydrophytes are found growing on nonhydric soils, and sometimes upland plants are found growing on hydric soils. The resource manager is confronted with making wetland designations where there are mixtures of hydrophytes and upland plants. The weighted average and index average methods of vegetation analysis, used in conjunction with the FWS Wetland Plant List (Reed 1986), provide a means of making such a designation. In this study, the results of WA and INAV were consistent with the hydric/nonhydric status of the soils and with hydrologic conditions at the study sites. Assessments of hydrology were qualitative. Three main types of hydrologic regime were recognized, including regular tidal inundation, seasonal ponding, and upland. Correlations between quantitative hydrologic data and WA and INAV vegetation analyses would be useful in future investigations regarding wetland delineation.

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APPENDIXES

Appendix A. Definition and criteria for hydric soils (SCS1985b).[a]

DEFINITION OF HYDRIC SOIL

A hydric soil is a soil that in its undrained condition is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation.

CRITERIA FOR HYDRIC SOILS

1. All Histosols except Folists, or

2. Soils in Aquic suborders, Aquic subgroups, Albolls suborder, Salorthids great group, or Pell great groups of Vertisols that are:

   a. somewhat poorly drained and have water table less than 0.5 ft from the surface at some time during the growing season, or

   b. poorly drained or very poorly drained and have either:

      (1) water table at less than 1.0 ft from the surface at some time during the growing season if permeability is equal to or greater than 6.0 inches/hr in all layers within 20 inches, or

      (2) water table at less than 1.5 ft from the surface at some time during the growing season if permeability is less than 6.0 inches/hr in any layer within 20 inches, or

3. Soils that are ponded during any part of the growing season, or

4. Soils that are frequently flooded for long duration or very long duration during the growing season.

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[a]See "References" section for references cited in appendixes.

Appendix B. Descriptions of soil series sampled (SCS 1972, 1977a, 1977b, 1981, 1985c, 1985d).

ALVISO SERIES: Fine, mixed, nonacid, isomesic Tropic Fluvaquents.

Alviso soils occur on the rims of marshes, north of Suisun Bay. The series consists of nearly level, poorly drained soils that formed in mixed alluvium. Elevation ranges from 0-3 m above sea level. Permeability is slow, and surface runoff is very slow. Typically, the profile is gray and dark gray silty clay loam to a depth of more than 1.5 m, and is saline throughout.

ANTIOCH SERIES: Fine, montmorillionitic, thermic Typic Natrixeralfs.

Antioch soils occur on terraces bordering Suisun Bay. The series consists of moderately well-drained soils that formed in alluvium from sedimentary rocks. Elevations are 3-15 m above sea level. Slopes are 0%-9%. Permeability and runoff are very slow. Typically, the surface layer is mottled gray loam 0.5 m thick; the subsoil is mottled brown clay 1 m thick; and the substratum is brown loam to a depth of more than 1.5 m.

BALLARD SERIES: Fine-loamy, mixed, thermic Typic Argixerolls.

Ballard soils occur on alluvial fans and bench terraces bordering San Pablo Bay. The series consists of very deep, well-drained soils that formed in mixed alluvium derived from sedimentary and igneous rock. Elevations are 3-90 m above sea level. Slopes are 0%-9%. Permeability is moderate, and runoff is medium. Typically, the surface layer is brown, gravelly loam 0.5 m thick; and the subsoil is brown, gravelly clay loam to a depth of 1.5 m or more.

JOICE SERIES: Clastic, euic, thermic Typic Medisaprists.

Joice soils occur in tidal marshes bordering Suisun Bay. The series consists of very poorly drained, organic soils that have a high mineral content. They formed from hydrophytic plant remains mixed with fine mineral sediments. Elevations are from 1.5 m below sea level to sea level. Slopes are less than 1%. The soils are flooded regularly by tides. Typically, the soil is black, clayey muck to a depth of more than 1.5 m.

NOVATO SERIES: Fine, mixed, nonacid, isomesic Typic Hydraquents.

Novato soils occur in tidal marshes throughout the study area. The series consists of deep, very poorly drained mineral soils that formed in alluvium deposited along the margins of bays. They are found at elevations of 0-3 m above sea level, and have slopes of 0%-2%. The soils are flooded regularly by tides, and are saturated throughout the year. Textures are silty clay loam, silty clay, or clay. Typically, the surface layer is gray with distinct reddish-brown mottles. Below 3-6 dm, the soil is gleyed from permanent saturation, appearing bluish-gray throughout. Organic matter decreases irregularly with increasing depth. Sulfidic material occurs 5-10 dm deep. The soil is mildly alkaline to strongly alkaline throughout and is noncalcareous. On soil survey maps published before 1985, those areas within the Reyes mapping unit that are not protected by levees and that are flooded regularly by tides would now be recognized as the Novato series. Reyes soils have been redefined to include only those soils that have been altered by diking and drainage.

OMNI SERIES: Fine, montmorillionitic, thermic Fluvaquentic Haplaquolls.

Omni soils occur on flood plains and basins throughout most of the study area. The series consists of very deep, poorly drained, calcareous soils that formed in alluvium from mixed rock sources. They are moderately high to high in organic matter, which has accumulated from hydrophytic plant remains. Elevations are 3-30 m above sea level. Slopes are 0%-2%. Permeability and runoff are slow, and the soils are subject to ponding. Omni soils are often calcareous near the surface. Typically, the surface

(Continued)

layer is grayish-brown silty clay 2-4 dm thick; the subsoil is mottled, gray silty clay 6-9 dm thick; and the substratum is mottled gray to olive-brown silty clay to a depth of more than 1.5 m.

PESCADERO SERIES: Fine, montmorillionitic, thermic, Aquic Natrixeralfs.
Pescadero soils occur on basin rims throughout most of the study area. The series consists of very deep, poorly drained soils that formed in alluvium derived from sedimentary rock. Elevations are 1-30 m above sea level. Slopes are less than 2%. Permeability and runoff are very slow, and the soils are subject to ponding. Typically, the surface layer is brownish-gray clay loam 1 dm thick; the subsoil is grayish-brown, saline-alkali clay and clay loam 1 m thick; and the substratum is gray clay loam to a depth of more than 1.5 m.

REYES SERIES: Fine, mixed, acid, thermic Sulfic Fluvaquents.
Reyes soils are in reclaimed and protected marsh areas throughout the study area. The series consists of deep, somewhat poorly drained mineral soils that formed in alluvium from mixed sources. Elevations range from 1 m below to 3 m above sea level. Slopes are 0%-2%. The soils are flooded during storms and extreme high tides. Permeability is slow; runoff is very slow. Textures are silty clay loam, silty clay, or clay. Typically, the surface layer is gray with distinct reddish-brown mottles. The region of mottling is thicker, and the gleyed zone deeper than in Novato soils. Sulfidic materials occur at depths of 5-10 dm. The soils are slightly to extremely acid, as a result of oxidation. On soil survey maps published before 1985, those areas within the Reyes mapping unit which are not protected by levees and which are flooded regularly by tides would now be recognized as the Novato series. Reyes soils have been redefined to include only those soils that have been altered by diking and drainage.

VALLECITOS SERIES: Clayey, montmorillonitic, thermic Lithic Ruptic-Xerochreptic Haploxeralfs.
Vallecitos soils are found in the Coyote Hills bordering San Francisco Bay, at elevations of 1-90 m above sea level, with slopes of 30%-50%. The series consists of shallow, well-drained upland soils that formed in residuum of medisedimentary rock. Permeability is slow, and runoff is rapid. Typically, the surface layer is brown, gravelly loam about 1.5 dm thick; and the subsoil is reddish-brown heavy clay loam extending to a depth of about 4 dm, underlain by sandstone bedrock.

Appendix C. Plant species list. Taxonomic nomenclature follows SCS (1982). The regional wetland indicator status (R-IND), for the California region, is taken from Reed (1986), except as noted otherwise. Each R-IND corresponds to a range of frequency of occurrence in wetlands, as defined in Table 6. A positive (+) or negative (-) sign following a R-IND more specifically indicates the higher or lower end of a particular frequency category. An asterisk (*) following a R-IND signifies that it is the best determination at this time, but that more information would be useful. Reed's (1986) list does not distinguish taxa beyond the species level, therefore, while subspecies and varieties are listed here, the R-IND given represents the species as a whole.

R-IND	Taxonomic name	Common name
UPL	*Aesculus californica* (Spach) Nutt.	California buckeye
UPL	*Ailanthus altissima* (Mill.) Swingle	Tree of heaven
UPL	*Aira caryophyllea* L.	Silver hairgrass
FAC	*Aquilegia formosa* Fisch. ex DC.	Sitka columbine
UPL	*Artemisia californica* Less.	California sagebrush
FACW	*Artemisia douglasiana* Besser	Mugwort
FACW	*Atriplex patula* L.	Orache, fathen saltbush
FAC	*Atriplex semibaccata* R. Br.	Australian saltbush
UPL	*Avena barbata* Brot.	Slender wild oat
UPL	*Avena fatua* L.	Wild oat
UPL	*Baccharis pilularis* DC. ssp. *consanguinea* (DC.) C. B. Wolf	Coyote bush
UPL	*Brassica nigra* (L.) W. Koch	Black mustard
UPL	*Brassica campestris* L.	Field mustard
UPL	*Briza maxima* L.	Rattlesnake grass
UPL	*Bromus diandrus* Roth	Ripgut grass
FACU*[a]	*Bromus mollis* L.	Soft chess
UPL	*Bromus rubens* L.	Red brome
OBL[a]	*Calystegia sepium* (L.) R. Br. ssp. *limnophila* (Greene) Brummitt	Marsh hedge bindweed
UPL	*Carduus pycnocephalus* L.	Italian thistle
UPL	*Centaurea melitensis* L.	Napa thistle
UPL	*Chlorogalum pomeridianum* (DC.) Kunth	Soap plant
UPL	*Convolvulus arvensis* L.	Common bindweed
FACW+	*Cotula coronopifolia* L.	Brass buttons
FACW, DRA	*Cressa truxillensis* H. B. K.	Alkali weed
OBL[b]	*Cuscuta salina* Engelm. var. *major* Yunck.	Marsh dodder
UPL	*Cynosurus echinatus* L.	Dogtail grass
FACW	*Distichlis spicata* (L.) Greene var. *stolonifera* A. A. Beetle	Saltgrass
FACU	*Elymus glaucus* Buckley var. *jepsonii* J. B. Davy	Blue wildrye
FAC+, DRA	*Elymus triticoides* Buckley ssp. *triticoides*	Creeping wildrye
UPL[a]	*Epilobium brachycarpum* Presl	Autumn willoweed

(Continued)

Appendix C. (Continued)

R-IND	Taxonomic Name	Common Name
UPL	*Eriogonum nudum* Dougl. ex Benth. var. *nudum*	Buckwheat
UPL	*Erodium cicutarium* L'Her.	Red-stem filaree
OBL,DRA	*Eryngium aristulatum* Jeps.	Beethistle eryngo
UPL	*Eschscholzia californica* Cham.	California poppy
FACW+	*Frankenia grandifolia* Cham. & Schlecht.	Alkali heath
UPL[d]	*Geranium* sp.	Geranium
OBL	*Glaux maritima* L.	Sea milkwort
FACW	*Grindelia humilis* Hook. & Arn.	Marsh gumplant
OBL*[a]	*Helenium bigelovii* Gray	Bigelow sneezeweed
OBL, DRA	*Heliotropium curassavicum* L. var. *oculatum* (A. Heller) I. Johnst.	Seaside heliotrope
FAC	*Hemizonia pungens* (Hook. & Arn.) Torr. & Gray ssp. *maritima* (Greene) D. Keck	Common spikeweed
FAC[c]	*Hordeum geniculatum* All.	Mediterranean barley
UPL	*Hordeum leporinum* Link	Hare barley
OBL	*Hydrocotyle verticillata* Thunb. var. *triradiata* (A. Rich.) Fernald	Whorled pennywort
UPL	*Hypochaeris glabra* L.	Smooth cat's ear
FAC, DRA	*Iva axillaris* Pursh	Poverty weed
OBL	*Jaumea carnosa* (Less.) Gray	Fleshy jaumea
OBL	*Juncus balticus* Willd.	Baltic rush
FAC	*Lactuca serriola* L.	Prickly lettuce
FACW*[a]	*Lepidium latifolium* L.	Perennial pepperweed
OBL	*Lepidium oxycarpum* Torr. & Gray	Sharppodded pepperweed
FAC*[a]	*Lolium perenne* L. var. *perenne*	Perennial ryegrass
FAC	*Lotus corniculatus* L.	Birdsfoot trefoil
UPL[d]	*Lupinus* sp.	Lupine
FAC	*Malvella leprosa* (Ortega) Krapov.	Alkali mallow
UPL	*Medicago polymorpha* L.	Bur clover
UPL	*Melica californica* Scribn.	California milkgrass
FAC, DRA	*Melilotus indica* (L.) All.	Sour clover
UPL	*Mimulus aurantiacus* Curt.	Bush monkeyflower
FACW+	*Monerma cylindrica* (Willd.) Coss. & Durieu	Thintail, sicklegrass
OBL	*Oenanthe sarmentosa* K. Presl ex DC.	Water parsley
FACW*[a]	*Plantago elongata* Pursh	Slender plantain
FACW+	*Plantago hirtella* H. B. K. var. *galeottiana* (Decne.) Pilg.	Mexican plantain
FAC-	*Plantago lanceolata* L.	English plantain

(Continued)

Appendix C. (Continued)

R-IND	Taxonomic Name	Common Name
OBL	*Polygonum hydropiperoides* Michx.	Mild-water pepper
OBL	*Polypogon interruptus* H. B. K.	Ditch polypogon
FACW+	*Polypogon monspeliensis* (L.) Desf.	Rabbitfoot grass
OBL	*Potentilla anserina* L. ssp. *egedii* (Wormskj.) Hiitonen	Silverweed
UPL	*Quercus garryana* Dougl. ex Hook.	Garry oak
FAC+	*Rosa californica* Cham. & Schlecht.	California wild rose
FAC-	*Rumex acetosella* L.	Sheep sorrel
FACW-	*Rumex crispus* L.	Curly dock
OBL	*Salicornia europaea* L.	Annual pickleweed
OBL	*Salicornia virginica* L.	Perennial pickleweed
OBL[a]	*Scirpus acutus* Muhl. ex Bigel.	Hardstem bulrush
OBL	*Scirpus americanus* Pers.	Olney's bulrush
OBL	*Scirpus californicus* (C. A. Meyer) Steud.	California bulrush
OBL	*Scirpus cernuus* Vahl	Low clubrush
OBL	*Scirpus robustus* Pursh	Alkali bulrush
UPL	*Silene gallica* L.	Windmill Pink
FAC	*Sisyrinchium bellum* S. Wats.	Western blue-eyed grass
OBL	*Spartina foliosa* Trin.	Pacific cordgrass
OBL, DRA	*Spergularia marina* (L.) Griseb.	Sand spurry
UPL	*Stipa pulchra* A. Hitchc.	Spear grass
UPL	*Taeniatherum caput-medusae* (L.)Nevskii	
UPL	*Torilis arvensis* (Huds.) Link	Hedge parsley
UPL	*Toxicodendron diversilobum*(Torr. & Gray) Greene	Poison oak
OBL	*Triglochin maritimum* L.	Seaside arrowgrass
OBL	*Typha angustifolia* L.	Narrow-leaved cattail
FACU[a]	*Vicia sativa* L.	Common vetch
UPL	*Vicia villosa* Roth	Winter vetch
FACW	*Vulpia bromoides* (L.) S. F. Gray	Brome
FACW	*Vulpia myuros* (L.) C. C. Gmel. var.*hirsuta* Hack.	Rattail fescue

[a] Updated regional wetland indicator status (P.B. Reed, FWS; pers. comm., 1987).

[b] Regional wetland indicator status assigned by author. *Cuscuta salina* is a parasitic plant not listed on the FWS Wetland Plant List (Reed 1986). This variety, *C. s. major*, occurs in coastal marshes mainly on *Salicornia* spp.

[c] Regional wetland indicator status assigned by author. *Hordeum geniculatum* is not listed on the FWS Wetland Plant List (Reed 1986), however, a synonymous name, *Hordeum hystrix*, is listed with a R-IND of FAC. I could find no reference indicating a taxonomic difference between the two, and I believe the two names represent the same species. Because both names are recognized by SCS (1982), the ommission of *H. geniculatum* from Reed's (1986) list could be erroneously interpreted as a R-IND of UPL. I have recommended to P.B. Reed that the name *H. geniculatum* be added to the FWS Wetland Plant List for the California region with a R-IND of FAC.

[d] Plants identified only to the genus level were assigned the driest indicator status for that genus.

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As part of a national study, vegetation association with known hydric and nonhydric soils was sampled along the San Francisco Bay in California. Data on the hydrolic conditions of each soil was also collected from each sample site. Weighted average and index average (presence/absence averages) values were calculated for vegetation associations on each soil using the method developed by T.R. Wentworth and G.P. Johnson at North Carolina State University. Five of the six hydric soils examined were designated wetlands by these analyses and the remaining hydric soil was in the wetland range, but required supplemental information to verify its wetland nature. All of the upland soils supported a preponderance of upland vegetation. Results of vegetation analyses were also consistent with hydrologic conditions on each soil.

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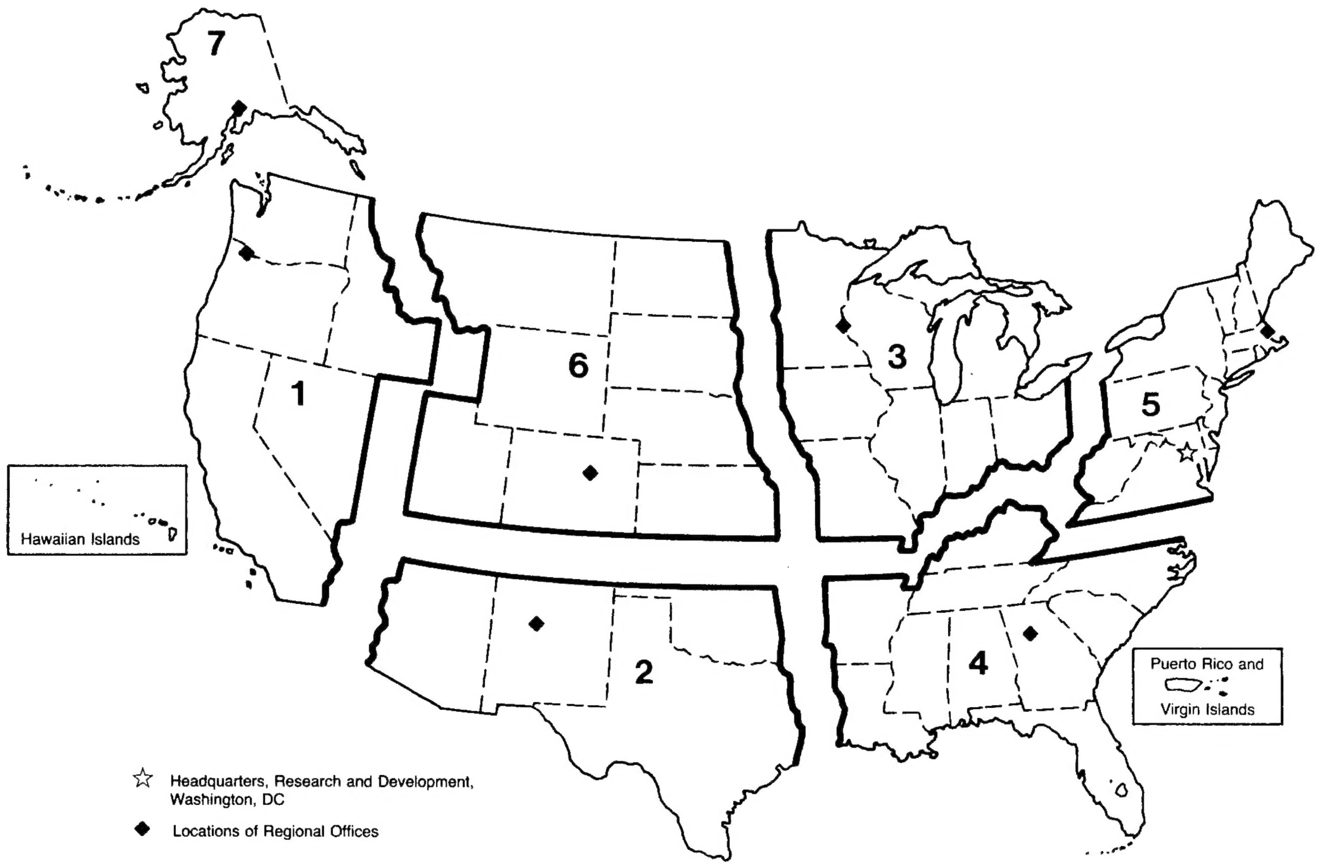

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